Lean Construction: Prospects for the German construction industry

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Abstract

There is little, if any, information available about the range and dissemination of lean concepts among construction companies in Germany. Building on the methodologies and conceptual frameworks used in earlier work in the UK (Common *et al.*, 2000) and the Netherlands (Johansen *et al.*, 2002) this study carried out a similar survey among German construction companies to discover the current understanding of lean principles, perceptions of lean and trends in lean development. Qualitative and quantitative analysis of an email questionnaire sent to large German construction companies indicates that there is little awareness of lean in the German construction industry and that hardly any company uses lean concepts on a company wide basis despite evidence that procedures and techniques that are used on German construction sites are generally consistent with lean construction practice. There appears to be cultural resistance to a manufacturing derived, production-system-view of construction.

Keywords: Lean construction in Germany, Lean penetration

Introduction

Lean concepts have been brought to the construction industries of Australia, Brazil, Denmark, Ecuador, Finland, Peru, Singapore, UK, USA and Venezuela (Ballard and Howell, 2003a). However, surveys in the UK (Common *et al.*, 2000) and the Netherlands (Johansen *et al.*, 2002) strongly suggest that the construction industry has generally been slow in taking up lean concepts. A comparison of the surveys also reveals that the two countries differ in their approach to lean construction (Johansen *et al.*, 2002). With regard to the German construction industry, there is little, if any, information available about the range and dissemination of lean concepts among construction companies.

The intention of this study is to conduct a survey among German construction companies to disclose the current understanding of lean principles, perceptions to lean and trends in lean development. In addition, the study is meant to reveal how far current practice and mentality affect the development of a lean culture and to see if the German experience has anything in common with that of the UK and the Netherlands.

The study basically followed Common et al's (2000) approach adopted during their UK survey. A quantitative technique was employed for collecting the data; followed

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by a qualitative, interpretative analysis. Data were gathered by conducting an e-mail survey with premier construction companies in Germany.

Background

Implementation of Lean Concepts in Construction

Implementing lean concepts means applying tools and techniques throughout the stages of a project. A theoretical foundation is provided through the transformation-flow-value view and further aspects of management theory and complexity theory. It seems, however, that implementing lean concepts requires a fundamental change of traditional structures in terms of both organisation and behaviour. Howell and Ballard (1998) advise us that one has to develop system thinking and to understand the difficulty of change mental models. What is more, one has to accept deep resistance to decentralised decision making. Garnett *et al.* (1998) made the point that what is often overlooked is that any organisational change process is put forward by people. During a collaborative implementation effort by seven Chilean construction companies as discussed by Alarcón and Diethelm (2001), Alarcón *et al.* (2002), and Alarcón and Seguel (2002) insights were provided indicating the need for commitment and ownership at all levels for the success of lean processes. Other studies show similar findings. For example, research on the introduction of Last Planner to a project in the UK raised structural and cultural problems, particularly with sub-contractors (Johansen and Porter, 2003). Considering the implementation of Last Planner from a sociological viewpoint Johansen *et al.* (2004) conclude that cultural barriers are still inherent in the industry. It appears that a substantial change has not taken place yet. Two surveys in the UK (Common, 2000) and in the Netherlands (Johansen *et al.*, 2002) suggested that the construction industry has generally been slow in taking up lean concepts. At the time the surveys were executed, construction companies had adopted lean principles only in a loose manner. Both studies revealed a limited knowledge of lean construction and varying perceptions among construction companies.

To sum up, the majority of the studies on lean implementation underpin the potential for improvement through 'leaner' construction. Equally they expose structural and cultural obstacles in encouraging people to adopt lean concepts. Changing traditions and behaviour, however, seems to be a necessary precondition for implementing lean construction.

The German Construction Industry

German construction has seen a declining investment trend over 10 years after the boom in early 1990's (Federal Office for Building and Regional Planning - Bundesamt für Bauwesen und Raumordnung, 2004). This trend is expected to continue. Information from the Federation of the German Construction Industry (*Hauptverband der Deutschen Bauindustrie*) indicates that the share of actual construction work carried out by the larger companies is declining. Bosch and Philips (2003) point out that the majority of the larger German building firms have developed into general contractors and building service companies. The common procurement method in Germany has changed to general contracting (Hochstadt, 2002). The larger companies take on the position of a project management organisation while the construction work itself is principally sub-contracted to smaller companies.

German industry is highly regulated. Construction work is primarily regulated by the German Building Contract Code (*Vertragsordnung für Bauleistungen, or VOB*). It is common practice in the German construction industry to base awarding procedures and contractual relations on the VOB (Bosch and Philips, 2003). A unique feature of the German construction industry is the monopoly of the master craftsperson, which "ties the management of building firms within the handicraft trades to proof of qualification and thus constitutes an important barrier to an increase in the number of low-qualified self-employed people, existing, for example, in the Untied Kingdom" (Bosch and Philips, 2003). The Handicrafts Code (*Handwerksordnung*) specifies who is allowed to set up such a business. The accelerated structural change in the industry, the poor economic progression and the intensified internationalisation of the market are expected to slow down the innovative capability of the construction industry (Hochstadt, 2002). In order to meet the challenges in the German construction industry, reforms have been implemented concerning primarily the vocational training and the Handicrafts Code (Bosch and Philips, 2003).

Research design & method

The questionnaire adopts a quantitative approach in which data are gathered to measure the extent to which principles, which might be considered "lean", have spread throughout the German construction industry. The objectives were to establish how lean techniques have been disseminated among construction companies, how lean thinking has penetrated the industry, and how lean concepts are being understood. To achieve these, data were collected from large companies which were considered to be more aware of and likely to be influenced by innovation on large projects. The questionnaire was sent out to project managers, managing directors or chief executives from 61 companies taken from *Top100 construction companies in Germany* (2005). A response rate of 28% was achieved.

The questionnaire was formulated in close relation to the UK survey (Common *et al.*, 2000). Their respondents had commented favourably on it, it had been successfully applied in the Netherlands later and thus, could be considered sufficiently tested.

However, the conceptual framework on which the British questionnaire was based in 2000 appeared to be insufficient in view of the progress of development in lean construction. The advancement in the field was taken into account by updating the framework accordingly (see *figure 1* later). Additionally, the formulation of the questions made use of a questionnaire developed for measuring a company's conformance to lean ideals by a team of researchers of the Construction Industry Institute (CII) (Diekmann *et al.*, 2003).

After completing the results they were informed further by discussions with one of the responding companies senior managers and with a member of LCI Germany.

Conceptual Framework

In their work Common et al (2000) identified four areas as being fundamental in developing a lean culture, namely Procurement, Planning, Control and Management. Within each area they recognised a number of techniques that were seen as being instrumental for the realisation of lean construction. The techniques documented included Design & Build, Last Planner, Lookahead Planning, Supply Chain Management and Partnering.

However, this framework was considered to be no longer sufficient due to the progress made since the study was carried out. Among the lean construction

community today there seems to be an improved understanding for the complexity of the industry and the mutual dependency of its participants. As a result implementation efforts have become more comprehensive. New insights have been gained into the development and application of techniques as well as into the human aspects of lean construction.

Taking into consideration the developments in lean construction up till now, the conceptual framework can now be viewed as comprising eight areas (*Figure 1*).

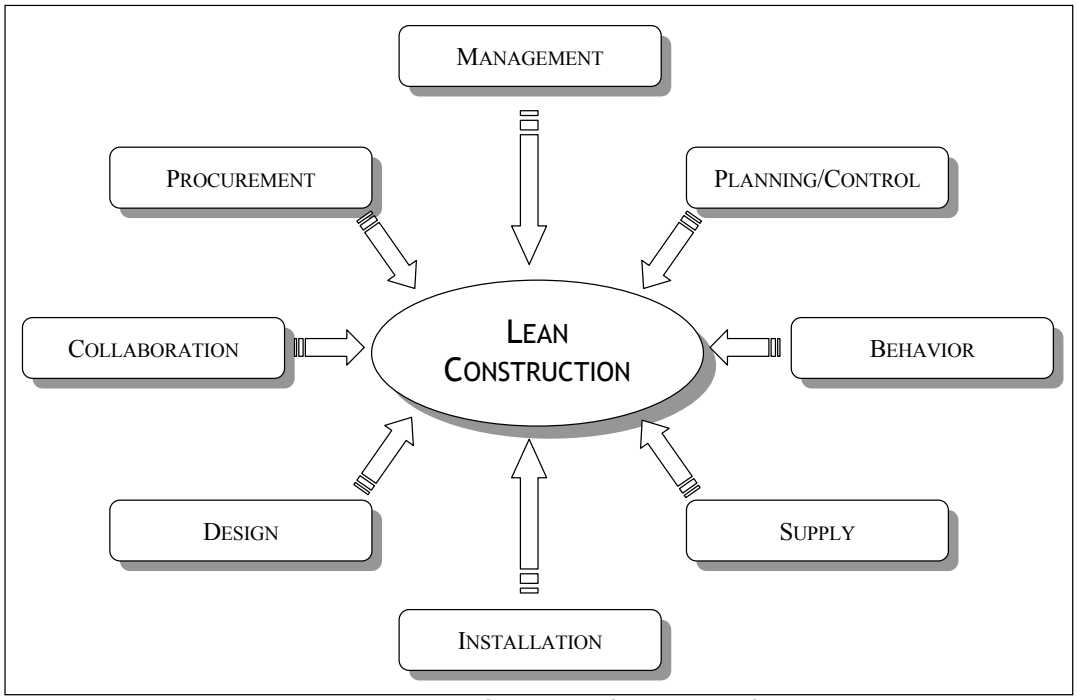

Figure 1: Conceptual Framework

Supporting background to the choice of these areas is given in Appendix A.

Research Results

Dissemination of Lean Concepts in Germany

Procurement

There is a dominance of general contracting although there is evidence that some companies are more involved in what might be considered to be "leaner" forms of procurement. More than three quarters of the responding companies (76%) indicated a share of annual turnover from general contracts above 20%. However, 41% of the responding companies realised up to 20% of their annual turnover through management contracts and/or design & build contracts. The respondents were also asked to indicate the routes adopted for the development of the design. Most frequently respondents delegate design work to external designers which tends to separate the design from the construction process and misses the lean aim of integration.

In general then, the actual state of the German construction industry in terms of facilitating the integration of design and construction by means of contracts and

design procedures appears to be at a rather early stage of lean construction development.

Management

A lean approach to construction management had been shown to be essential for adopting a holistic system view to the project as well as to the project's temporary network of service and product providers. In this respect several management tools/concepts have been acknowledged. Within the questionnaire these were listed and the respondents were asked to mark those they are currently involved in.

With 35% TQM seems to be the tool which is most frequently applied within the German construction industry, followed by Benchmarking and Concurrent Engineering. The Last Planner Initiative and Supply Chain Management amount to just 12% each, while Value Streaming has not been indicated at all. The data from the survey also show that 76% of the responding companies are employing either none or just one of the listed lean management concepts. Having identified these as incorporating fundamental lean principles into construction, the current situation in the German construction industry in terms of lean construction management could be considered poor.

The practice of visual management on construction sites, however, appears to be advanced. In the survey the respondents were asked to specify the company's position regarding availability and accuracy of visual information on site. The results illustrated in imply that on most construction sites in Germany information about schedule, quality, safety, productivity and project status are posted and if so, the documents are generally kept up-to-date.

Planning / Control

The underlying principles of planning and control methods in traditional construction and in lean construction could hardly differ more. While the predominant use of the traditional method CPM has been recognised as willingly introducing waste to construction planning, lean tools such as Value Streaming, Last Planner and Lookahead Planning are known to reduce waste and to continuously improve construction activities. Therefore, questions in the survey were directed at planning and control methods as well as improvement measures on site.

The evaluation of the data shows that the customary technique employed within construction planning remains the Critical Path Method. A frequent application of this network planning method was indicated by most of the respondents (62%). In comparison, a frequent application of VS was declared by just 15% of the respondents. Interestingly, about every second respondent, it seems, has never heard of at least one of the "leaner" methods.

The focus of one of the survey questions was on measures taken to systematically quantify unused materials and supplies before disposing, reclaiming or returning them. The aim of another question was to find out whether there are measures in place to assure quality objectives. The evaluation of the responses indicates no more than a modest advance in the verification of unused materials and supplies, the utilisation of quality plans appears to be well developed. Thus, one could claim that, on the majority of construction sites in Germany, certain procedures are maintained which might be considered as conforming to lean.

Collaboration

Throughout the study the high demand for effective communication and collaboration practices in lean construction has been emphasised. A wide range of

collaboration technologies has been put forward with reference to lean construction. It is argued that a frequent use of collaboration technology would point towards lean conformance. How frequently German companies are applying collaboration technologies to construction has been established

The results demonstrate that management systems for electronic data are regularly employed by the companies participating in the survey. Project Information Systems are also used within a reasonable level, bearing in mind that a third of the respondents picked “mostly” (25%) or “always” (8%) for this tool. Less popular are text or video conferencing technologies as well as 3D Studios and VR Tools.

Taken as a whole, the situation in the German construction industry in terms of utilising collaboration technology can be seen as progressive. However, the findings from the study give the impression that the focus is on exchanging electronic data rather than applying sophisticated design technologies.

Behaviour

The respondents were asked to specify to what extent employees are sharing their thoughts and if the upper management is generally committed to change. It seems that an open exchange of ideas and views among employees is a common habit in the German construction industry. This can be seen as facilitating the change process during the implementation of lean concepts. Only a minority of the respondents (6%) appear to be convinced that employees do not share their thoughts at all. In terms of willingness to change, the results show the upper management to be generally committed to changes within the company.

With regard to these behavioural aspects it could be hoped that, as far as the attitudes of people involved are concerned, the aim of transforming a traditional construction company in Germany into a lean construction company are not without prospects. However, there are more than just a few other aspects of human behaviour that needed to be looked at before this statement could be generalised.

Design

The respondents were asked if they used “lean” tools such as DSM, 3D Studios or VR in the design process.

Design Structure Matrix is hardly used at all to optimise the order of design tasks. Thirty-one percent of the respondents stated they never used this technique and to 62% of the respondents it was complete unknown. However, 8% of those using DSM were employing it at all times. This might mean that there is a high potential for improving the design process.

Supply

The respondents were asked to indicate their use of SCM, Value Streaming, JIT and Partnering. Partnering seems to be well established within the industry with 47% claiming to be involved in this concept.

The application of JIT as one of the management concepts was document by just 24% of the respondents. Considering that this concept has been known to several industries for decades, this result is disappointing. The concept of SCM is also little used (12%).

Overall the results show that the German construction industry lacks a comprehensive lean approach to supply. Most disturbing of all is the apparent disregard of value aspects. In spite of this, the good level of partnering activities and

the existing number of applications of JIT might be considered as indicating a tendency towards lean supply.

Installation

In terms of a lean assembly process on site the importance of reliable and constant flows of work and resources has been stressed. The techniques proposed to achieve this, focus on appropriate site organization, pre-assembly strategies, and synchronization of task and input flows. A selection of such techniques was presented in the questionnaire and the respondents were asked whether they ever applied any of them to the installation process or whether any body else in the company did so.

The coordination of deliveries is common practice in most German construction companies. The employment of the 5S process to the construction site was declared by only 16% of the respondents.

In addition to the list of techniques for improving the assembly process, two sets of opposite statements were given in the questionnaire. One set drew attention to the arrival of materials on site (just-in-time) and the other set was concerned with the handing over of completed work products between crews (flow processing). The respondents were asked to rate their company's attitudes regarding the differing statements.

In most cases materials seem to reach the site shortly before they become installed. Furthermore, completed work packages are made available to the next crew in small batches or at best in a continuous stream. Thus, the synchronisation of task and input flow appears to be well developed.

To sum up, practices on German construction sites give the impression that there is general agreement with lean assembly principles.

Understanding and Depth of Penetration

In order to determine the level of understanding and depth of penetration of lean concepts within the German construction industry the survey questionnaire was also subjected to an interpretative analysis. The questionnaire was structured to facilitate interpretation through cross linking particular issues of lean construction.

Integrating Design and Construction

The results presented in the previous section revealed that the general contract remains the traditional procurement form. A considerable share of the annual turnover made up from design & build was indicated by only two of the responding companies. Thus, the German construction industry seems to be far from an ideal situation of applying lean techniques, as the traditional procurement forms do not facilitate lean approaches to project planning and execution.

With regard to the management of the design process the situation appears just as insufficient as in procurement, as design work is mainly passed on to consultants. Techniques applied in lean construction, however, support concurrent design and planning. This will possibly be impeded when design work is sub-contracted.

Furthermore, the frequent application of the planning technique CPM reflects an inadequate development stage in terms of the understanding of lean principles. Factors that are important for project planning (e.g. transportation, waiting time, rework) are abstracted away when using this method. Techniques that have been recommended for lean planning are rarely used or completely unknown. No more than two companies professed a regular use of some of the lean planning techniques.

The findings point out that a limited understanding of the underlying principles of integrated design, planning and construction exists within the German construction industry. Facilitating procurement forms are rarely used and neither construction design nor planning seems to be completely managed fully in accordance with lean principles.

Holistic Perspective

A second issue that was addressed within the questionnaire was the holistic perspective of lean construction, which has been reflected in the recommendation of comprehensive management concepts. The professed application of these concepts within the individual companies reveals whether construction companies are taking a holistic approach to construction or whether these management concepts are only applied occasionally.

The largest number of respondents indicated the application of either none or just one of the management concepts. An employment of three or more of these was documented by the minority of the companies. From these results it could be argued that a holistic understanding of construction activities might not have been developed yet.

The results also show that little, if any, attention has been paid to value flow, supply chains and lean planning techniques in construction. This remains consistent throughout the survey results. Advancement is only shown on the subject of collaboration and quality aspects of construction.

Customer Value

One section of the survey drew attention to how the respondents believe customer value could best be achieved. The combination of answers revealed the approach the respondents regarded most important to create value for the client.

Interestingly, none of the respondents declared Design, Value Streaming or SCM as important disciplines for providing value for the customer. This is coherent with previous responses, bearing in mind that design and construction are commonly separated and that value generation and flow management concepts tend to be underdeveloped.

A typical set of disciplines selected by the respondents would be Site Production and Quality Assurance in combination with either Planning or Site Management. Both combinations can be perceived as focussing on the production system while emphasising the quality aspect of construction. It could be argued that all of these activities are concentrating on maintaining value and therefore improving the process. However, overlooking that value is created in the design stage and all the way through supply chains probably make an advanced production system inefficient.

It appears that there is no predominant focus on contracts as far as issues of customer value are concerned.

Demand for Change

It has been said that the environment of the construction industry has become increasingly demanding over the last years. The processing of modern-day projects is almost certainly determined by an increasing technological and financial pressure along with a rising interest of the client to be involved in the process. One section in the survey was set out to expose if contractors are aware of these demands and of the need of changing current practices.

An increased demand for lower project costs was identified by all respondents and over 50% recognised growing exigencies concerning faster turnover. In addition, over two thirds of the respondents associated higher demands with technological aspects of construction projects. With regard to client involvement no necessity for change was indicated by the largest number of respondents.

It becomes clear from the responses that the contractors are generally aware of the demands that have been put upon them. Therefore, it could be inferred that they recognise an obvious need for change and may be open minded towards the application of lean concepts in the future.

Perception and Application of Lean Principles

In one question the respondents were asked how they considered the transferability of lean principles to construction. In a further question they had to specify to what extent they thought lean principles were already used within the respective company.

The majority of the respondents expressed scepticism towards the applicability of lean principles by declaring that just a few lean principles could be put into operation within the construction industry. Nevertheless, many of them claimed to consider the future use of lean principles, what may show a growing interest in lean construction.

Only three companies thought that most of the lean principles are applicable to construction. These companies also professed they were using lean concepts as far as contract terms permit. However, the evaluations of the responses that were made throughout the questionnaire exposed that only one of these companies may be considered “lean”.

Discussion

It appears that conversion thinking still governs the German industry and that the integration of lean related project processes has not taken place. This is mainly reflected in conventional procurement methods and the frequent utilisation of planning and control techniques that are responsible for large amounts of waste in construction. The results also give the impression that there is limited understanding of the complexity of the industry network and its potential for improvement. Management concepts that have been proven efficient in the construction industries of other countries are still little used. In particular, the efficiency of mapping techniques and supply chain management has been disregarded.

Looking at German construction sites, it seems, there is general agreement with the lean philosophy. Principles of transparency are implemented and measures are taken to guarantee build-in-quality. Also the production process occurs in a continuous flow while materials are customarily pre-fabricated and delivered at the appropriate time. The responses also indicate a good attitude towards change.

Overall, the results imply good conditions regarding installation, modest conditions in terms of collaboration and behaviour, and inadequate conditions on the subjects of procurement, management, planning/control, design and supply.

Apparently the German construction industry has a lot to catch up on in the way it manages its activities. The greatest deficiency appears to be the narrow perspective contractors might have regarding value generation in general and effective management of the network of service and product providers in particular. However, as far as the implementation of lean construction on the production level is

concerned the German construction industry seems to provide a good foundation. Usually the workforces are highly skilled due to the level of education set out by the Handicrafts Code, which facilitates the compilation of multi-skilled work crews. Furthermore, certain lean practices are already in place, so it might be easier to find a way of approaching the lean ideal.

When comparing the findings from the present study with the results of the surveys undertaken in the UK (2000) and in the Netherlands (2002) no significant difference becomes apparent regarding the level and application of lean concepts. In the UK survey Common et al (2000) found that there is "… a distinct lack of understanding and application of the fundamental techniques required for a lean culture to exist." Johansen *et al*. (2002) concluded that, in the Netherlands; "Lean, as a concept appears to be largely unknown although some issues associated with it have some low penetration of the industry. Some companies indicate that a few principles could be applied but there is no indication that they have gone beyond thinking of introducing them." This also describes the situation emerges in the German construction industry.

Supposing that lean construction in the UK and the Netherlands has not been developed much since the surveys were carried out, one could argue that there are certain characteristics existent in all three countries that hinder lean practices to advance. In a telephone conversation between one of the authors and a member of the LCI in Germany, the argument was raised that the level of economical and technological progress of a country influences the development of lean construction (Ott, 2005). Following this it was stressed that some of the countries where lean concepts have successfully been implemented (e.g. Brazil or Chile) are employing more workers and using less technology than, for example, German or UK construction companies do. Thus, it could be argued that lean construction is more effective when implemented in countries which are more people focused than technology focused. However, this argument would need verification since major improvements have been achieved with lean construction in technology driven countries like Australia, Denmark and the USA.

Conclusions and Recommendations

Maylor (2003) suggest that the issue for the modern project manager is the need for a holistic approach to project management. That is, to consider project management to be more than managing the sequence of steps required to complete the project on time and on budget. With lean construction such a holistic approach has been introduced to construction which goes far beyond traditional project management by facilitating a new understanding of construction activities and the industry itself. In recent times, the construction industries of several countries around the world have taken on a lean approach to construction.

The intention of the research at hand was to investigate lean construction in the context of the German construction industry. There was little data available about the development of lean construction in this country. An investigation of the application and understanding of lean concepts and techniques among German construction companies was undertaken to fill the gap in the existing body of knowledge.

In an initial step a thorough analysis of the literature on lean construction relevant to the study provided useful insight into the origin of the lean philosophy as well as the emergence and the consolidation of lean construction. Based on the findings from the literature review a conceptual framework has been developed, which formed the

basis for two questionnaire surveys. The received questionnaires were then subject to a qualitative and an interpretative analysis in pursuit of the objectives of the study.

The research suggests that there is little awareness of lean in the German construction industry. No more than a few lean concepts are occasionally applied within the industry. Therefore, the level of how lean concepts penetrate the construction industry is rather low.

An overall evaluation of the questionnaires shows that hardly any company uses lean concepts on a company wide basis. Profound deficiencies were revealed relating to procurement methods and the management of construction projects. Owing to traditional contracting and certain planning methods large amounts of waste are still inherent in the German construction industry. Moreover, the potential for improving the company's performance through employing advanced management concepts such as supply chain management or concurrent engineering, it seems, has not been realised.

On the other hand, the research implies that procedures and techniques that are used on German construction sites are generally consistent with lean construction practice. In particular, aspects regarding build-in-quality and the flow of materials and work crews that are relevant during the assembly process seem to be considered.

However, the majority of the respondents took a critical stand towards the applicability and transferability of lean principles to the construction industry. This might indicate a persistent view of construction as an industry, which can make very little use (if any) of principles that have been developed in the manufacturing industry. Thus, the most difficult barrier to overcome appears to be the mental change process towards a production-system-view of construction.

Recommendations

The present study identifies that the level of development and application of lean construction in the German construction industry has been very low. The UK survey and the Netherlands survey indicated similar findings. In the discussion of the results the argument was put forward whether the development of a lean culture is easier said than done in countries where construction activities are mainly technology focused compared to those where the construction process is people focused. Here further research is recommended. A possible starting point could be Hofstede's four dimensions of national culture – Power Distance, Uncertainty Avoidance, Individualism and Masculinity and Femininity (Hofstede, 1984).

In order to facilitate the development of lean construction in Germany research is considered fundamental that focus on the implementation of individual lean concepts in the context of the construction industry. While doing so, the consideration of the prevailing conditions (i.e. supplier-contractor and client-contractor relationships, the regulatory framework, etc.) are regarded as important.

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APPENDIX A

Background to Figure 1

Having acknowledged the focus on flow processing as being essential for lean construction, the **procurement method** adopted should smooth the progress of design and construction in such a way that they can take place concurrently. Moreover, the procurement method should enable early involvement of downstream players in the upstream process. In this respect integrated procurement strategies such as Design & Build, Management Contracting, Private Finance Initiatives and Partnering have been identified as most effective. In contrast, traditional contracts (e.g. general contracts or sub-contracts) tend to separate the design from the installation process and also the participants within.

In terms of the development of **management concepts** in lean construction much emphasis was given to improving information transparency, managing key service provider, and initiating improvement strategies. Here the principles of Supply Chain Management, Concurrent Engineering and Total Quality Management – previously used solely in the production industry – have been recognised as successfully applicable to the construction industry. Benchmarking could be added as a management concept relevant to lean construction, since it helps to improve performance and competitiveness. The importance of the visualisation of processes and practices as well as the positive consequences of a simplification of procedures has been acknowledged by introducing principles such as Visual Management and Standardisation to the management of construction.

Further techniques that are significant for lean construction have been established in project **planning and control**. These techniques aim at the reduction of variability and uncertainty inherent in construction. Planning and control have been combined, because control in lean construction is primarily achieved by accurate planning near to the execution of the task. The Last Planner System of production control has been identified as the leading concept. Among others the system unifies techniques such as Work Structuring, Pull Scheduling, Lookahead Planning and Weekly Work Planning. Although it may be possible to employ some of these techniques separately, it has been recognised that they are most effective when applied together. This includes the techniques of Constraints Analysis and the Activity Definition Model, which usually come into play during the preparation of look-ahead schedules. With regard to the planning of site activities Continuous Flow Processing has proven very beneficial.

Another fundamental feature of lean construction is **collaboration**. This term covers many aspects from long-term contractual agreements with sub-contractors, suppliers, consultants and clients, via the formation of multi-disciplined teams for a

project, to the joint use of information technology for several deliveries or document exchanges. Techniques and tools found to facilitate the collaboration aspect of lean construction include Partnering, Cross-functional Teams and the employment of Document Management Systems or Project Information Systems.

While considering **behavioural aspects** of lean construction it emerged that a successful transformation from conventional practice to lean construction requires participation and dedication from all hierarchical levels, as well as the ability to critically analyse the structure and culture of one's own organisation. These requirements can be generalised as 'commitment to change' and the 'ability to self-criticism'. It has further been acknowledged that certain lean planning techniques demand a 'long-term vision'; others require the 'sharing of incomplete information'. Both aspects were accredited as crucial for the process, but difficult to achieve.

The lean approach to **construction design** was found to employ techniques that help to prevent value loss by diminishing inconsistent decision-making and to stimulate flow by enhancing coordination and information procedures. Techniques that focus on improving decision-making have been identified as Concurrent Design (of the product and the process) and a
Set-based Design strategy. The implementation of Design Structure Matrix, Virtual Design Studios and Virtual Reality Tools were made out as supporting co-ordination and information procedures in lean design.

With regard to the provision of materials to the construction site, **supply principles** have been outlined that facilitate the delivery of materials at the appropriate time, of the desired quality and to the right amount. Apart from advanced information technology typical techniques of lean supply have been acknowledged as Just-In-Time and Kanban. In addition it has been noted that the depiction and evaluation of the entire value stream of supply chains (Value Stream Analysis) improve the delivery process and the product itself.

The organisation and execution of the **installation process** in lean construction has been recognised as primarily following flow principles. This applies to the movement of work crews and materials as well as to the production processes themselves. CFP and the LP have been identified as techniques for planning and organising site tasks and crew movements. First Run Studies and Pre-Fabrication Strategies have been considered as minimising uncertainty in production processes. Regarding the effective administration of the necessary materials on site, the utilisation of a site logistic tool such as the 5S-Method has been proofed helpful.